The linear expansion coefficient

Introduction

The aim of the exercise is to study the phenomenon of thermal expansion of bodies and determination of the linear expansion coefficient for various materials.

Thermal expansion of materials with an increase of temperature must be predicted in many typical situations. When, for example, the bridge is subject to large seasonal temperature changes, the bridge sections are separated by expansion slots, thanks to which the sections are able to expand on hot days and shrink on freezing days without distorting the bridge. In another example, when the dental cavity is filled, the filling material must have the same thermal expansion properties as the surrounding tooth. Otherwise, consuming hot or cold meals would lead to tooth degradation. A similar situation takes place in the case of reinforced cement concrete, consisting of steel rods and concrete.

Solids, liquids and gases change their linear dimensions during heating. Apart from a few exceptions, the linear dimensions of solids increase with increasing temperature. The increase in the length of a solid body is directly proportional to the length of this body at the initial temperature and to the temperature increase (in small temperature ranges). Mathematically, this relationship can be written in the following form:

$$\Delta l = \alpha l_0 \Delta T, \tag{3.1}$$

where:

- α - linear expansion coefficient,
- Δl - length increase,
- l_0 - initial length,
- ΔT - temperature increase.

From the transformation of the 3.1 formula, we obtain the desired coefficient α, which has the dimension of the inverse of the temperature and is equal to the relative increase in length caused by the unit temperature increase.

$$\alpha = \frac{\Delta l}{l_0 \Delta T} \ . \tag{3.2}$$

A set of measuring equipment

A dilatometer is used to measure a linear elongation. The main part of the set is the pipe in which a metal rod is placed. The investigated rod is located between the micrometer screw on one side and the digital micrometer on the other side. The end of the rod that stays in contact with the micrometer screw is stationary. The other end touches the sensor. During heating, the rod expands. If the micrometer scale has been set to zero before the measurement, the elongation value is automatically displayed with an accuracy of hundredth of a millimeter. Rod heating is carried out by passing hot steam through the pipe. This steam is produced in a screwed kettle and then transported to the pipe using flexible hoses. To ensure water tightness, the space between the ends of the rod and the pipe is clogged with rubber stoppers.

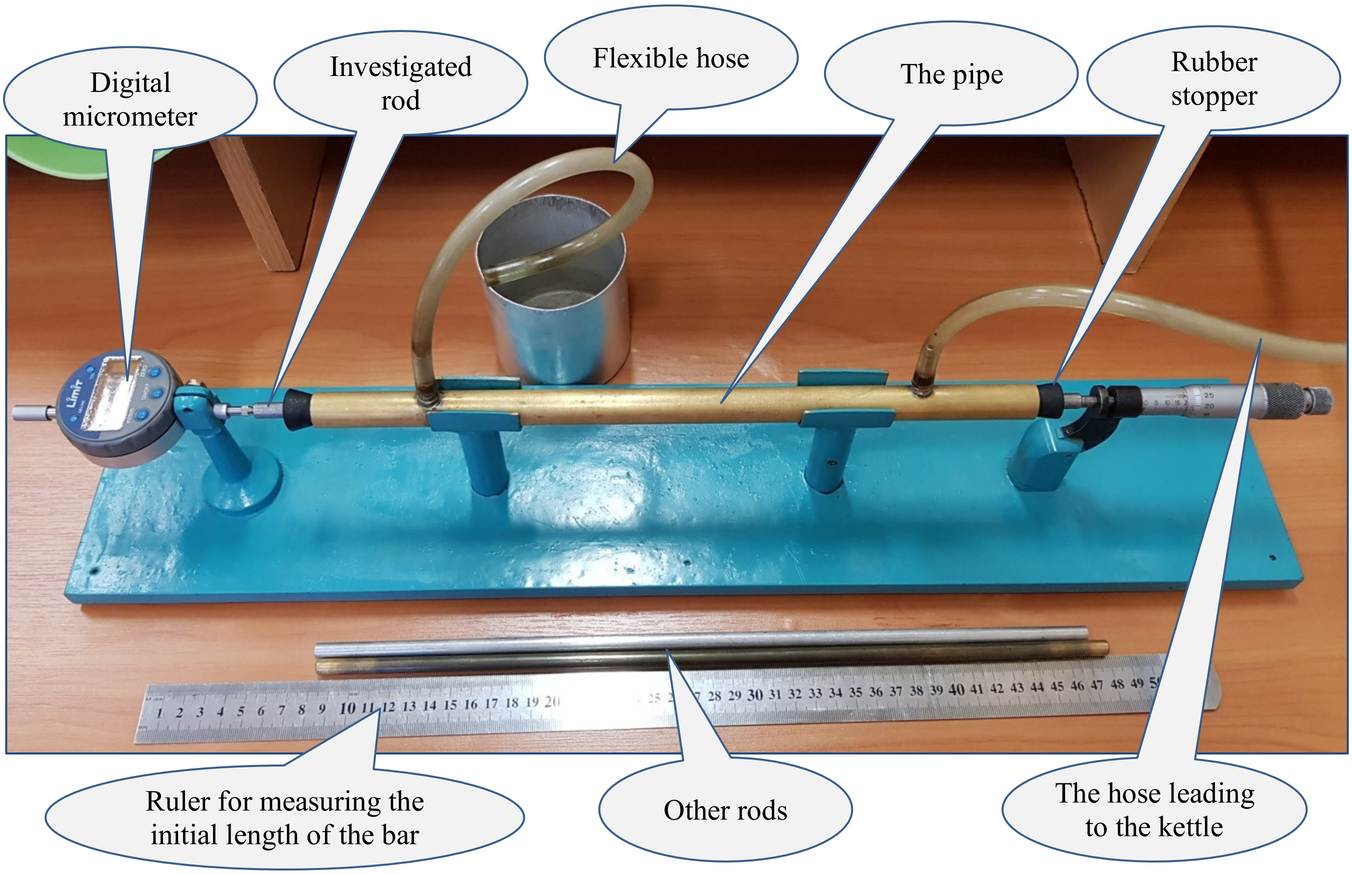

Fig. 3.1 Photo of the measuring set.

Proceeding

1. Measure the initial lengths (l_0) for all tested rods (Aluminum, Steel, Brass).
2. Use the thermometer located on the wall to read the room temperature (T_0). Assume that the temperature of the rods is the same.
3. Read the atmospheric pressure from the barometer located on the wall. From the table 1 of dependence of the boiling point of water on the pressure, read the boiling temperature (T_1). Calculate the temperature increase $\Delta T = T_1 - T_0$.
4. After boiling water and setting the value on the micrometer's display read the increase of the length of the rod (Δl).

Table of measurements and calculation results

The material from which the rod is made	l_0 (m)	T_0 (K)	T_1 (K)	ΔT (K)	Δl (m)	α (1/K)

Table 1 Dependence of the boiling point of water on the pressure

Pressure	Temperature	Pressure	Temperature	Pressure	Temperature	Pressure	Temperature
(hPa)	(ºC)	(hPa)	(ºC)	(hPa)	(ºC)	(hPa)	(ºC)
962	98,55	982	99,12	1002	99,69	1022	100,24
964	98,60	984	99,18	1004	99,74	1024	100,29
966	98,67	986	99,24	1006	99,80	1026	100,35
968	98,72	988	9929	1008	99,85	1028	100,40
970	98,78	990	99,35	1100	99,91	1030	100,46
972	98,84	992	99,41	1012	99,96	1032	100,51
974	98,90	994	99,46	1014	100,02	1034	100,57
976	98,95	996	99,52	1016	100,07	1036	100,62
978	98,99	998	9957	1018	100,13	1038	10067
980	99,07	1000	99,63	1020	100,18	1040	100,73

Processing of the results

1. Using the formula 3.2 calculate the linear expansion coefficient for each rod.
2. Estimate the uncertainties u(l_0), u(ΔT), u(Δl). When estimating u(ΔT), the influence of u(T_2) can be omitted but it is worth to take into account that the ends of the rod, during measurements, are outside the hot interior of the pipe.
3. Using the uncertainty transfer law for uncorrelated quantities calculate the combined uncertainty of the linear expansion coefficient $u_c(\alpha)$:

$$u_c(\alpha) = \sqrt{\left(\frac{u(\Delta l)}{l_0 \cdot \Delta T}\right)^2 + \left(\frac{-\Delta l \cdot u(l_0)}{l_0^2 \cdot \Delta T}\right)^2 + \left(\frac{-\Delta l \cdot u(\Delta T)}{l_0 \cdot \Delta T^2}\right)^2}.$$

4. For each of the examined materials compare the obtained value of the linear coefficient of expansion with the reference one. Considering the concept of expanded uncertainty check, if they are consistent.

Supplementary literature

1. Andrzej Kubiaczyk, Evaluation of Uncertainty in Measurements, Warsaw University of Technology, http://www.if.pw.edu.pl …